Lead Feature

The Crawley Power Meter

*By Derek Atter MIEE, CEng, G3GRO**
*and Dr Stewart Bryant BSc, PhD, DIC, MBA, FIEE, CEng, G3YSX***

RELIABLE AND accurate RF power measurements are an important facility for anyone involved in RF projects. Power meters capable of operating at relatively high power (over 1 watt) are readily available, but little attention has been given to amateur techniques capable of accurate power measurement at lower power levels. The Crawley Power Meter is capable of direct measurement of powers in the range -9dBm to +22dBm (125µW to 150mW) with an accuracy of about of 1dB (~20%). It has a frequency response that is flat to within 1dB up to 280MHz. This design, based on readily available components, needs only a digital multi-meter (DMM) to calibrate it.

Crawley Power Meter with digital readout, shown with its external RF head.

AMATEUR POWER MEASUREMENT

TECHNIQUES FOR the accurate measurement of RF power have been studied in considerable depth in the electronics industry. For a good review of the available techniques and the issues involved in achieving accurate results, take a look on the web at the Hewlett-Packard Test and Measurement Group site [1].

Most of the amateur power meter designs that operate in the power and frequency ranges that we are considering have involved the use of diodes operating at the limit of their IV characteristics into a high impedance [2]. The more sophisticated designs use a matched pair of diodes in a thermally compensated arrangement [3]. Some designs used logarithmic amplifiers (for example the RSSI output of a Philips NE604), although until the recent introduction of the Analogue Devices AD8307 [4], most cost effective instruments had a top end frequency limit of about 50MHz. These diode and log amplifier instruments measure voltage, not true RMS power, and are calibrated by measuring the output of a signal generator which must itself be externally calibrated. By contrast, the instrument described in this article is a true RMS power meter, and can be calibrated with a DMM.

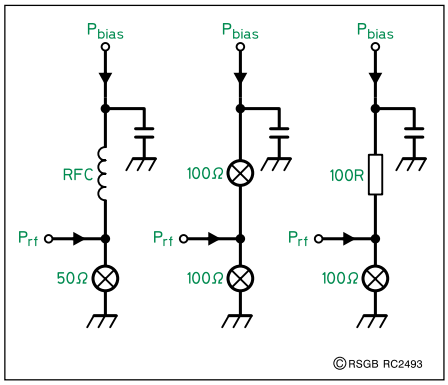


Fig 1: (a) G4COL single bulb RF sense head, (b) the two bulb approach, and (c) the approach used in the Crawley Power Meter.

The basic sensing element in the Crawley Power Meter is a small light bulb held at constant temperature and hence constant resistance, by a biasing circuit. The use of light bulbs in RF power measurement goes back to the early days of radio [5]. The technique typically involved dissipating the RF power in a bulb and then optically comparing the brightness of the bulb to a matched bulb fed by a metered DC supply. When the bulbs were of equal brightness, the DC power was equal to the RF power. Unfortunately, the resistance of a bulb varies significantly with the filament temperature and hence with the RF power applied. This in turn means that the device under test is subject to varying and unspecified loads.

An example of the use of a bulb as the sense element in a power meter is the design published by Ian Braithwaite, G4COL [6]. Ian's design, which was limited by the inductance of the sense element to about 30MHz, used in effect a simple analogue computer to calculate the RF power. He later published a simpler derivative of this design [7]. This later instrument used manual balancing and required the user to measure the voltage across the bulb, both with and without RF

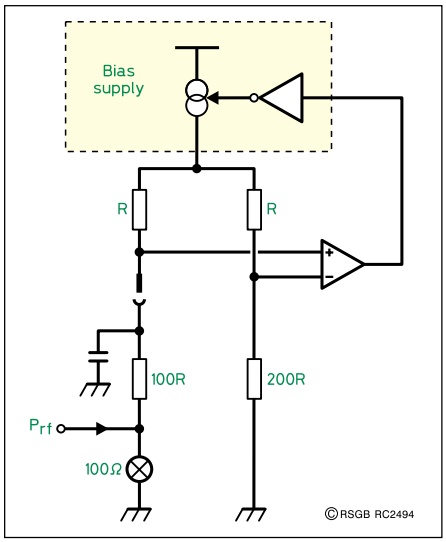


Fig 2: The RF sense head with bridge-controlled DC bias.

** 1 Little Crabtree, West Green Crawley, Surrey RH1 7HW.*
E-mail: DAtter@compuserve.com
*** 3 Redstone Park, Redhill, Surrey RH1 4AS.*
E-mail: SFBryant@iee.org.uk

power. Some calculation was then required to determine the RF power from these measurements. We investigated the latter design in some depth and were impressed by both its dynamic range and high-end frequency response (over 144MHz), both of which had been understated in the reported results. In the G4COL designs, a single bulb was used to measure the RF power level (**Fig 1a**).

The bulb used was a relatively large MES screw-in type torch bulb (nominally 6.0V, 0.1A, 60Ω), and the inductance of the coiled filament, together with its associated wiring, determined the upper frequency limit. In addition, these instruments used a choke to isolate the RF path from the DC bias circuit. The construction of this choke is critical to avoid unwanted losses and resonances, especially over an extended frequency range.

At a Crawley Amateur Radio Club presentation on G4COL's instruments, G0SQF referenced an article [8] using a two-bulb approach, based on a bridge (**Fig 1b**). This arrangement has three advantages.

1. The RF load consists of two bulbs in parallel. This allows the choke, along with its stray reactance, to be eliminated.

2. By using two very small bulbs, each dissipating half the power, it potentially reduces the stray reactance, which in turn tends to increase the useful operating frequency range.

3. Since the two bulbs are operated in series at DC, each bulb can be run at a higher resistance (ie 100Ω each) and hence lower current.

A mathematical analysis of the design (Appendix 1) showed that it was possible to obtain a linear reading of power without the need for a multiplier, either in the form of an analogue computer or a pocket calculator. The final refinement to the design (**Fig 1c**) was the realisation that one of the bulbs could be replaced by a resistor and, contrary to our intuition (but not our mathematics), would not affect the sensitivity of the instrument. This removed the need for a matched pair of bulbs and marginally increased the VHF performance (resistors have lower inductance).

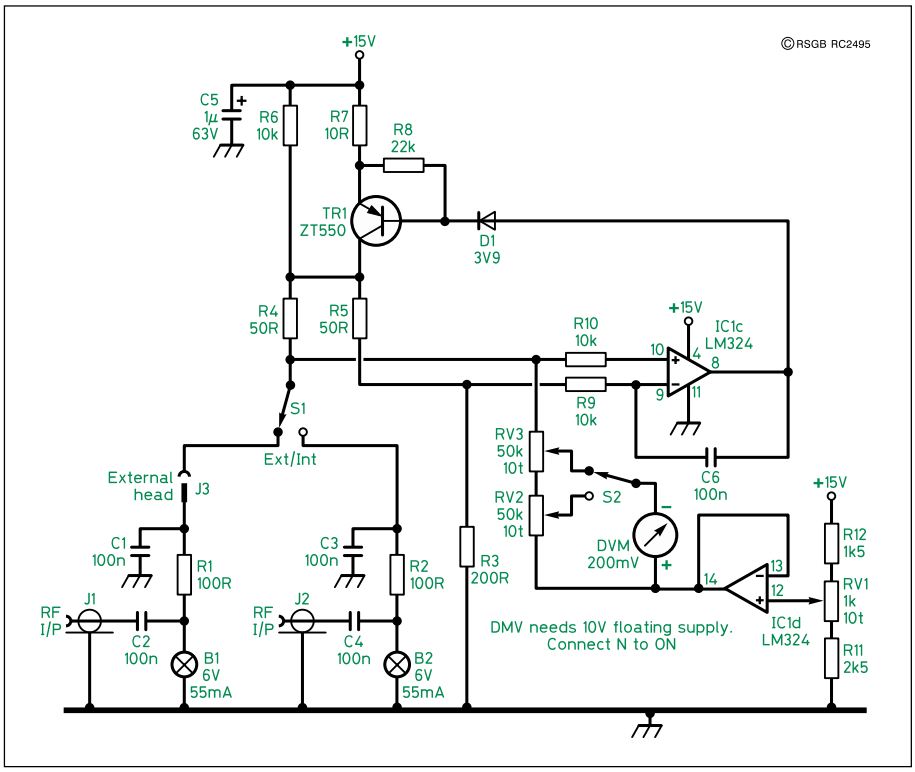


Fig 3: Power measuring circuit for the digital version of the Crawley Power Meter.

COMPONENTS

(Digital version)

Resistors (all fixed resistors, 0.6W 1%)

R1, R2	100R
R3	200R
R4, R5	50R
R6, R9, R10	10k
R7	10R
R8	22k
R11	2k5
R12	1k5
RV1	1k 10-turn panel mounting
RV2, RV3	50k 10-turn pre-set

Capacitors

C1, C2, C3, C4, C6	100nF 50V disc ceramic
C5	1µF 63V electrolytic

Semiconductors

IC1	LM324
TR1	ZT550
D1	3V9 400mW Zener

Miscellaneous

DVM	200mV DVM module with floating inputs (ie PM-128 from Vann Draper)
B1, B2	6V 55mA wire ended bulb (RS part 587-068)
J1, J2	BNC panel socket
S1, S2	SPDT toggle

POWER SUBSTITUTION TECHNIQUE

THE CRAWLEY Power Meter and the instruments described in [5], [6] and [7] all use a power substitution technique. This technique works by measuring the reduction in DC bias power needed to maintain the sense element at constant resistance when the sense element is heated by the dissipation of RF power. With these instruments we can calculate RF power dissipated by the sense element as:

$$P_{rf} = P_{\text{bias with no rf}} - P_{\text{bias with rf applied}}$$

Normally in commercial designs, the sense element is either a resistive thin film element or a thermistor, but these are expensive and difficult to source. In the Crawley Power Meter we used a small wire-ended 6V 55mA bulb in place of the thermistor. This has a nominal resistance of 110Ω. We placed the RF head in a bridge circuit, which then automatically adjusts the applied bias to the level necessary to maintain the resistance of the bulb filament at 100Ω (**Fig 2**). In this circuit, a voltage controlled constant current source biases both the sensor head and a 200Ω reference resistor. When the bias is such that the bulb has a resistance of 100Ω, the total resistance of both legs of the bridge will be 200 + RΩ, equalising the currents in both legs, and hence balancing the bridge. A differential amplifier compares the voltage across both legs of the bridge. Its output voltage controls the current source. Note that the simplest realisation of this instrument requires an inverting current source in which the current is inversely proportional to the control voltage.

OPERATION

THE BRIDGE operates as follows:

As the current flowing through the bulb increases so does its resistance, increasing the voltage across the bulb and its series 100Ω resistor. This increases the voltage applied to the positive input of the differential amplifier, which in turn increases the control voltage applied to the constant current source, reducing its current.

As the current through the bulb reduces, so does its resistance. This reduces the voltage across bulb, which brings the circuit back to balance. Similarly, if the current through the bulb decreases, so does its resistance, which causes the differential

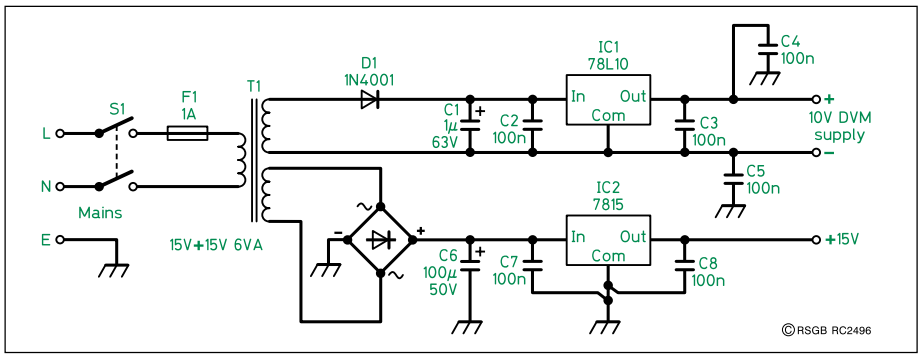


Fig 4: Power supply circuit.

amplifier to increase the applied current to restore balance.

Finally, you should notice that the RF head (the bulb, its 100Ω series resistor, and the de-coupling capacitor) needs only two connections (bias and ground) to the main instrument. This makes it simple to connect a remote sense head via a length of screened cable.

In Appendix 1 you will see that for this design of RF sense head, the change in bias voltage is directly proportional to the input RF power. We show that the relationship is approximately:

$$P_{rf} = 10V\Delta V \text{ mW}$$

where:

- P_{rf} is the RF input power in mW,
- V is the voltage across the sense head (bulb + 100Ω resistor) without RF power, and
- ΔV is the difference between the voltage across the head with and without RF power.

DIGITAL POWER METER

THE CIRCUIT for the digital version of the Crawley Power Meter is shown in **Fig 3**. The internal RF head consists of C3, C4, R2 and B2, and the external head consists of C1, C2, R1 and B1. Because of the small DC voltage changes that need to be measured, and to keep RF out of the bridge balancing circuitry, the external head is connected to the power meter via a length of 50Ω coax, using BNC connectors. S1 selects between the two available heads. R3, R4 and R5 form the remainder of the bridge. R3 sets the series resistance of B2+R2 (or B1+R1) at bridge balance. The choice of value for R4 and R5 is a compromise. The larger they are the more sensitive the bridge will be to the out-of-balance condition. However, increasing the resistance of these components also increases the voltage needed to drive the bridge. R1 and R2 must dissipate 50% of the RF power under measurement and hence must have both good RF characteristics and be capable of dissipating the necessary power. The accuracy of R1 through R5 is critical to the accuracy of the power meter as a whole. They must all dissipate the necessary power and yet remain at their designed values. In the prototypes, we used 0.6W 1% metal film resistors for these components. Power dissipation of the instrument could be improved by proportionally scaling R3 and R5, but care must be taken that they do not have a resistance that is significant compared to the input impedance of the bridge balance circuit. Making the two halves of the bridge identical is the conservative approach.

A controllable constant current source consisting of TR1, R7 and R8 supplies bias power to the bridge. Because TR1 is a PNP transistor, the current is inversely proportional to the control voltage. The bridge balance detector IC1c controls the constant current source. Op-amp IC1c measures the difference between the current flowing in the two halves of the bridge. When the bridge is balanced, the voltage at S1 will equal the voltage at the junction of R3 and R5. R9 and R10 isolate the bridge from the Op-amp. The output voltage of the Op-amp settles at the voltage necessary to drive sufficient current through the bridge. Because the base voltage that TR1 needs to achieve the balance is close to the +15V supply, a Zener diode (D1) is used to provide an offset, moving the required Op-amp output voltage closer to the supply voltage mid-point. R6 bypasses the constant current source and ensures that even when TR1 is turned off a small current always flows through the bridge. This prevents latch-up on power-up, or when switching measurement heads.

The reference voltage (the term V in the analysis) is set by RV1. A second Op-amp connected as a voltage follower sets the impedance of this voltage reference close to zero, providing isolation between the reference voltage and the operation of the bridge and voltage measurement circuitry. RV2 and RV3 are a potential divider that scale the difference between the bridge output and the reference output (ie they scale ΔV). The DVM module measures this scaled voltage. The DVM module needs a floating power supply of approximately 10V. On the DVM module the 'N' pin must be connected to its 'ON' pin to enable the display of the sign of the voltage difference. The voltage scaling was relatively large on the 200mW range and relatively small on the 20mW range. However, it was also quite variable, depending on the exact voltage that was needed to set the bulbs to 100Ω. We opted to use a pair of 10-turn preset potentiometers (RV2 and RV3) rather than the more conventional approach of cheaper pre-sets with series resistors. In analysing the operation of this circuit further, you should note that the input impedance of the DVM module is in excess of 10MΩ. For the purpose of calculating the necessary setting of RV2 and RV3, the presence of the DVM can therefore be ignored.

Fig 4 shows the power supply circuit. Because a 15V supply was needed to provide the necessary headroom in powering the RF heads, operation from the standard 13.8V supply found in most amateur radio stations was not possible. We therefore elected to provide a suitable internal mains power supply. T1 is a 15V 6VA transformer with two separate windings. One winding provides the 15V supply using a standard bridge and integrated voltage regulator arrangement. The isolated 10V supply for the meter is generated using the other winding and a half-wave rectifier. Because the current consumption of the DVM module is extremely low, a battery could have been use instead. In this case, a relay should be used to automatically disconnect the battery when the instrument is not in use.

ANALOGUE POWER METER

SOME CONSTRUCTORS may prefer the use of an analogue meter to display the measured power. **Fig 5** shows the analogue version of the power meter. The bridge, the controllable constant current supply, and the reference voltage supply are identical to the digital power meter design. The DVM

COMPONENTS

(Power Supply)

Capacitors

C1	1µF 63V electrolytic
C2, C3, C4, C5, C7, C8	100nF 50V disc ceramic
C6	100µF 50V electrolytic

Semiconductors

IC1	78L10
IC2	7815
D1	1N4001
D2	50V 1A bridge rectifier

Miscellaneous

T1	15V + 15V 6VA mains transformer
S1	DPST mains switch
F1	1A

COMPONENTS

(Analogue Version)

Resistors (all fixed resistors, 0.6W 1%)

R1, R2	100R
R3	200R
R4, R5	50R
R6, R9, R10, R13, R14, R17	10k
R7	10R
R8	22k
R11	2k5
R12	1k5
R15	1M
R16	100k
R18, R19	See text
VR1	1k 10-turn

Capacitors

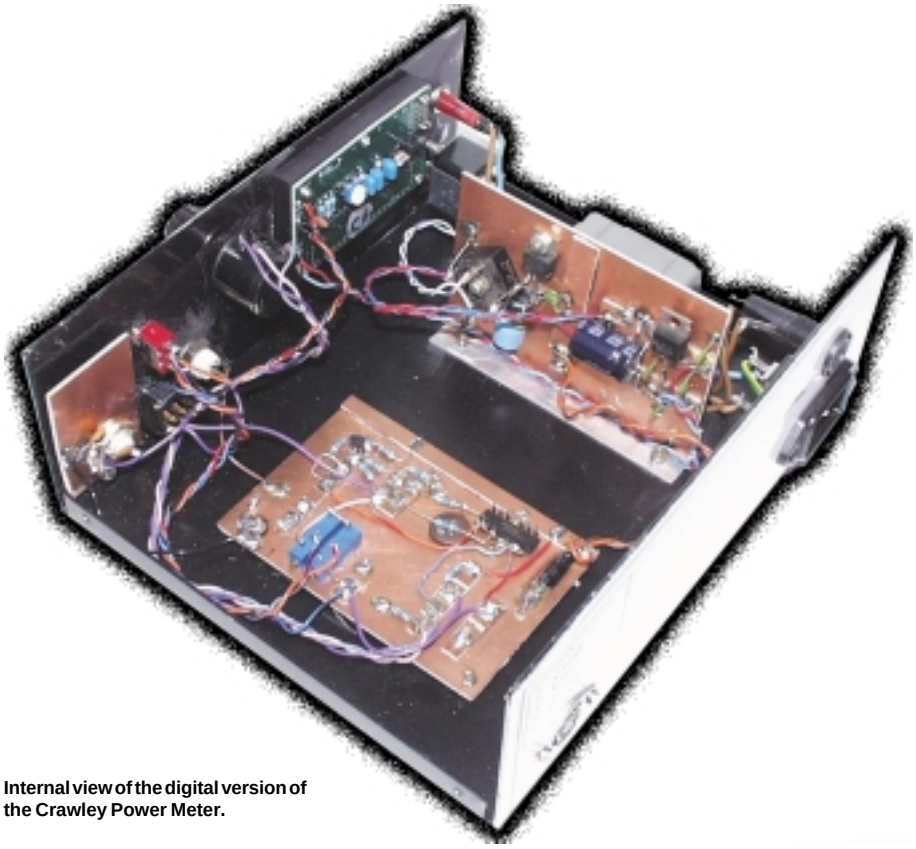
C1, C2, C3, C4, C6	100nF 50V disc ceramic
C5	1µF 63V electrolytic
C7	4.7µF 63V electrolytic

Semiconductors

IC1	LM324
TR1	ZT550
D1	3.9V 400mW Zener
D2, D3	1N914

Miscellaneous

Meter 1	100µA
B1, B2	6V 55mA wire ended bulb (RS part 587-068)
J1, J2	BNC panel socket



Internal view of the digital version of the Crawley Power Meter.

is replaced by an inverting amplifier with pre-settable gain (IC1a), and a voltmeter consisting of a 100µA meter with a series resistor (R18 or R19). The amplifier is operated at a convenient gain that is a multiple of ten. The voltmeter series resistors are set to achieve the correct calibration, compensating for the meter's internal resistance.

On the 300mW and 100mW ranges, a gain of one is needed, so the feedback resistor (R17) is made equal to the inverting input resistor (R13). On the 30mW and 10mW ranges a gain of ten is used so that the same voltage is read by the voltmeter. Similarly, on the 3mW range, a gain of 100 is required. In order to apply some meter damping, C7,

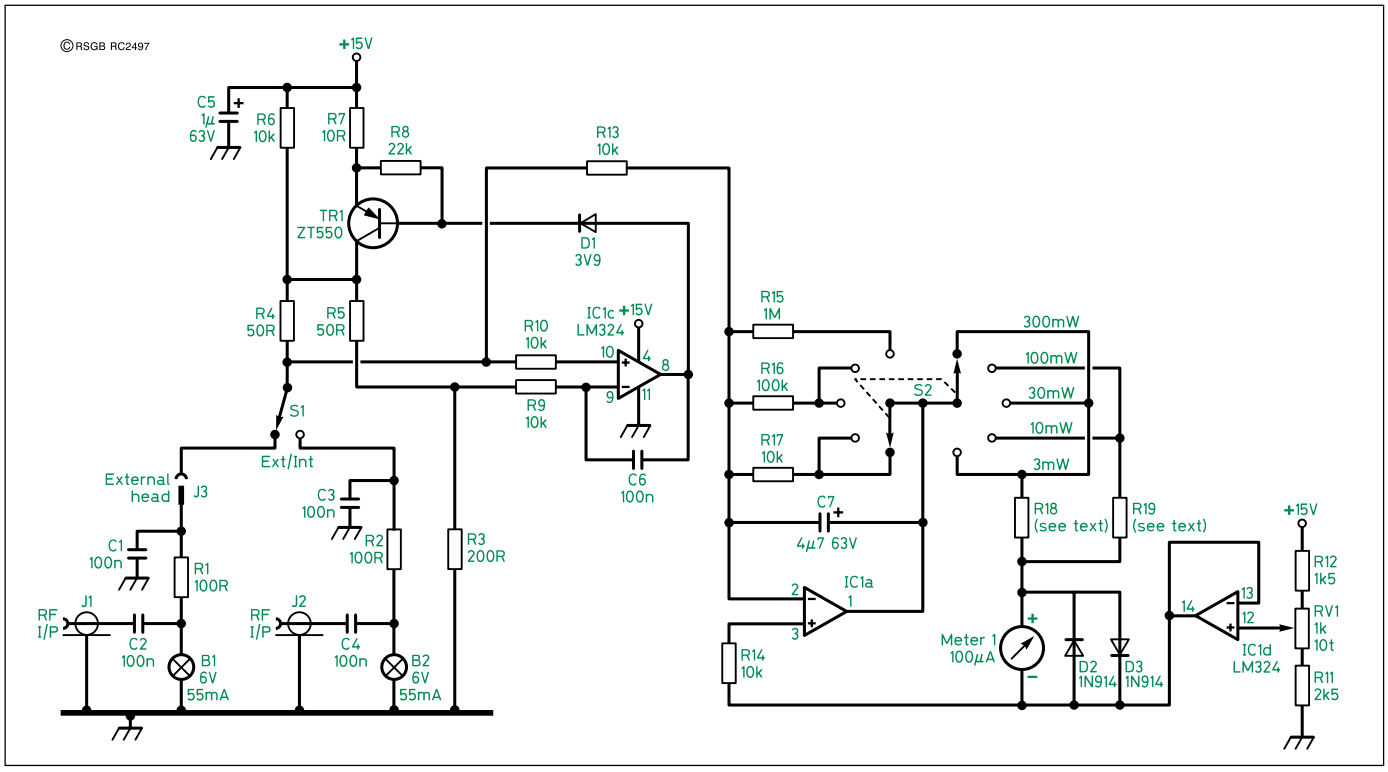
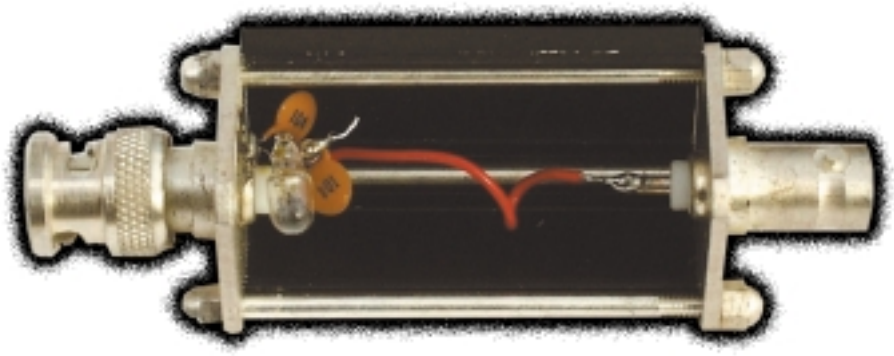


Fig 5: Analogue power meter circuit.



Internal view of the external RF head.

connected in parallel with the feedback resistor, provides an integration function. The amplifier must measure the difference between the voltage on the RF head and the voltage on the reference line (the output of IC1d). The non-inverting input is connected to the reference voltage via a 10k resistor to minimise an effect called 'input offset voltage'.

The process for setting the voltmeter resistors R18 and R19 is first to measure the quiescent voltage across the RF head, and to use this to determine the voltage at the meter for the given measured power. If we assume a head voltage of 9.6V, then we know that with a 300mW input, the change in voltage on the RF head would be 3.125V (using the relationship $P_{rf} = 10V\Delta V$mW - see Appendix 1). Since on this range the amplifier has a gain of one, we need to set R18 such that 100µA flows through the meter when the 3.125V is applied to it. If a 100µA meter is used this means that the total resistance of the meter plus R18 must be 31.25k [9]. The value can either be realised by directly selecting a suitable resistor (using standard values in series/parallel, as needed), or, preferably, by using a lower value resistor in series with a variable resistor. Similarly, on the 100mW range, the differential voltage will be 1.04V and the required value for R19 will be 10.42k. The meter movement, which should be scaled 1-3 and 1-10, is protected by a pair of back-to-back diodes, D2 and D3.

The analogue power meter only needs a single 15V power supply.

CONSTRUCTION

TWO COPIES OF the Crawley Power Meter were constructed, one digital and one analogue. The only critical area of construction is the RF heads. Here, careful choice of components and good RF practice in construction is critical to achieving good high frequency characteristics. In particular, lead lengths should be minimised.

We soldered the input coupling capacitor (C4) directly to the input socket and then soldered the bulb directly to its other lead, soldering the ground lead of the bulb directly to the body of the BNC input socket. Similarly, the lead lengths of R2 and C3 were minimised. The resultant 'birds nest' had the lowest inductance that we could achieve with these components, and correspondingly the best HF response. With one prototype, we placed the RF head on the main board, connecting it to the bulkhead BNC socket with a short length of miniature 50W coax. Unshielded lead lengths at one end were about 5mm at the board, and about 10mm at the socket, limited by the physical size of the components. When we carefully measured the frequency response, we found a 20dB null at about 143MHz. Reconstructing the head directly on the bulkhead connector removed all traces of this problem.

Construction of the bridge, readout and power supply is relatively simple and not critical. Any preferred technique - PCB, stripboard or 'dead bug' may be used. We both chose the dead bug approach. Although this is not as aesthetically pleasing as a PCB or stripboard approach, the solid groundplane, short lead lengths and low parasitic capacitance makes it ideally suitable for one-off RF and very low voltage designs. The number of wires needed is relatively small, so construction is not particularly onerous.

APPEARANCE

TO ACHIEVE A professional appearance for the finished project, a computer package was used to produce the artwork for the front and back panels. A laser print of the artwork was glued to the panel metalwork using a transparent spray-on adhesive. When dry the panel was covered with a transparent plastic film of the type that is sold for covering books. Provided care is taken to avoid stretching or tearing the plastic surface when mounting components on the panel, the result is a durable and attractive finish. A copy of the panel artwork with suitable drilling marks inscribed may be tacked over the panels and used as a template to ensure the correct hole alignment with the final panel artwork.

The calibration of the Crawley Power Meter depends directly on the exact voltage at which the resistance of the bulb is 100Ω. In some cases a number of heads might need to be build for the power meter (eg, you might wish to provide remote monitoring, to include the sense element in an attenuator, or to experiment with a frequency-compensating network to extend the HF response). In this case a simple jig can be constructed to measure the bias voltage when no RF is applied. The RS Components bulbs that we used were supplied in batches of 10. From each batch a couple of pairs that were matched to within 100mV (0.2%) were selected. The construction of this jig is not critical (it operates at DC). The power meter drives the jig using the external head socket.

All the components needed for this project are readily available. The only critical components are the bulbs. These are available from RS Components, which trades on the amateur electronics market as Electromail. If you are unable to source these bulbs, they should be substituted by the smallest wire-ended 6V 55mA bulbs available. If a different type of bulb is used, an accurate calibration run must be undertaken to verify that a satisfactory HF response has been achieved.

CALIBRATION

CALIBRATION OF THE digital power meter is achieved by setting the 10 turn pre-set resistors (RV2 and RV3) such that they satisfy the scaling equation derived in Appendix 1:

(equation 1)

Where V is the voltage across the RF head when no RF power is applied and V_m is the DVM voltage required when power P_{rf} is applied. R1 represents the resistance across the DVM module (which is dominated by the setting of RV2 and RV3), and R_1+R_2 is the total resistance of RV2 plus RV3.

To calibrate the power meter, first measure the voltage across the RF head with no RF power applied using a DMM. Then measure the series resistance of RV2 and RV3, again using a DMM. Using equation (1), calculate the required settings for RV2 and RV3.

As shown in Appendix 1, one of our instruments needed a resistance ratio of 0.0961 on the 200mW range. In this case the resistance of RV2 and RV3 in series was 94k, thus the resistance across the DVM module when S2 was switched to the 200mV range need to be 0.0961 x 94k = 9.03k. A DMM was used to measure the resistance between the positive terminal of the DVM module and the slider of RV2. RV2 was adjusted until a resistance of 9.03k was measured. Similarly, on the 20mW range, a resistance of 90.3k was needed between the slider of RV3 and the positive terminal of the DVM module. ♦

To be continued...

The Crawley Power Meter

*Final part, by Derek Atter MIEE, CEng, G3GRO**
*and Dr Stewart Bryant BSc, PhD, DIC, MBA, FIEE, CEng, G3YSX***

IN THE FIRST part details were given of how the method of measuring power was decided upon. This was followed by two versions of the project, one employing a digital display and the other employing a meter movement.

In this part we will provide details of how well it worked, plus some supplementary information.

RESULTS

THE PERFORMANCE of the meter was evaluated by using it to measure the output of an Adret 730A signal generator. This signal generator is unusual in that it has a maximum power output of 23dBm at frequencies up to 180MHz. A calibration run was made with 17dBm (50mW) output over the frequency range 1 to 180MHz at 0.5MHz intervals. **Fig 6** shows both the indicated input power and the error in this value (multiplied by ten to get it to a satisfactory scale). These measurements show that the RF head is accurate to with ±1dB (±20%) up to 180MHz.

To investigate the HF response of the power meter further we measured the power output of a Marconi TF 2015 signal generator. This instrument covers 10 to 520MHz, with a maximum output of 800µW. We first calibrated the output level of this signal generator over the range 10 to 360MHz using an HP435A power meter. We then measured its output at 10MHz intervals up to 360MHz. **Fig 7** shows the error in the measured frequency for the internal and the external heads. Our results showed that both power heads were within 1dB of each other and had less than 1dB total error at all frequencies up to 280MHz. A third head using two bulbs instead of one bulb and a resistor produced similar results, although the 1dB HF cut-off occurred about 40MHz lower in frequency. This showed that the RF measuring heads were reproducible and capable of covering most of the VHF spectrum.

The dynamic range of the power meter was checked at 10MHz using the Adret 730A signal generator. **Fig 8** and **Fig 9** show the measured vs actual power and the error in the measurement (multiplied by ten) on the 200mW and 20mW ranges respectively. On the 200mW range the readings were correct to within 1dB between 0dBm and 22dBm (1mW and 160mW respectively), and were within 0.5dB for most of this range. At the low power end of the measurements, the increased error was due to having insufficient significant digits on the DVM. The response of the 20mW range was found to have a negligible error down to -5dBm, rising quite sharply to 1dB error at -9dBm (300µW and 125µW respectively). To achieve accurate measurement at these lower power levels it was necessary to compensate for offset drift by recording the meter reading without RF before and after the power measurement and averaging the results. These results show a dynamic range in excess of 30dB for an error of 1dB Attenuators can be used to extend the range to higher powers. Extending the range to lower powers would either require significant analogue design effort to reduce the bias power drift or the use of a dynamic compensation approach.

** 1 Little Crabtree, West Green Crawley, Surrey RH1 7HW.*
E-mail: DAtter@compuserve.com
*** 3 Redstone Park, Redhill, Surrey RH1 4AS.*
E-mail: SFBryant@iee.org.uk

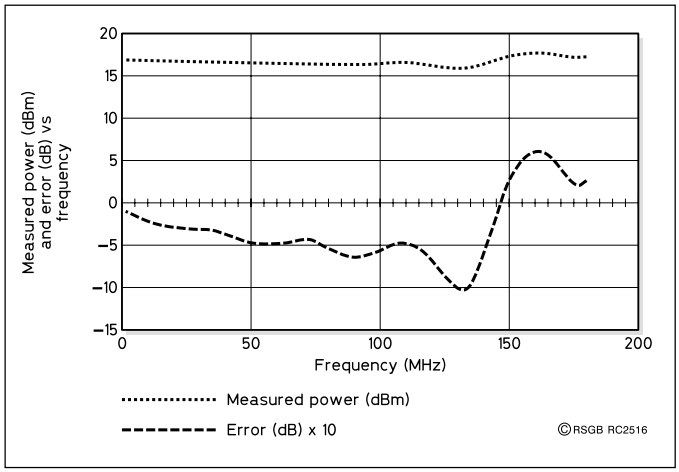


Fig 6: Measured power (dBm) and error (dB) vs frequency with 17dBm input.

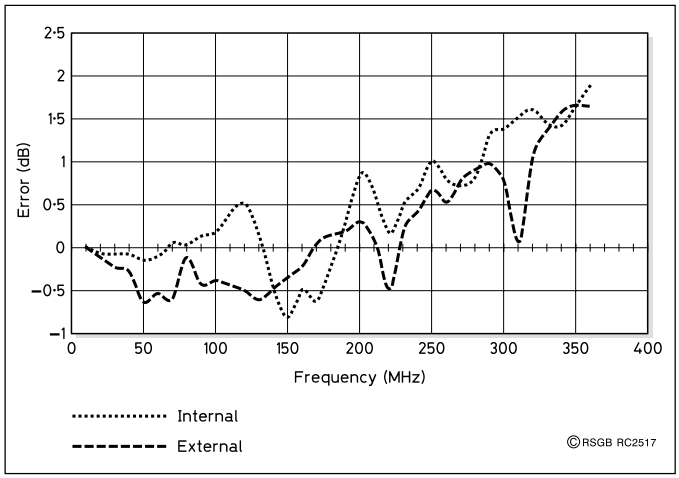


Fig 7: Error (dB) vs Frequency (MHz) for internal and external power measuring heads at approximately 800µW input power.

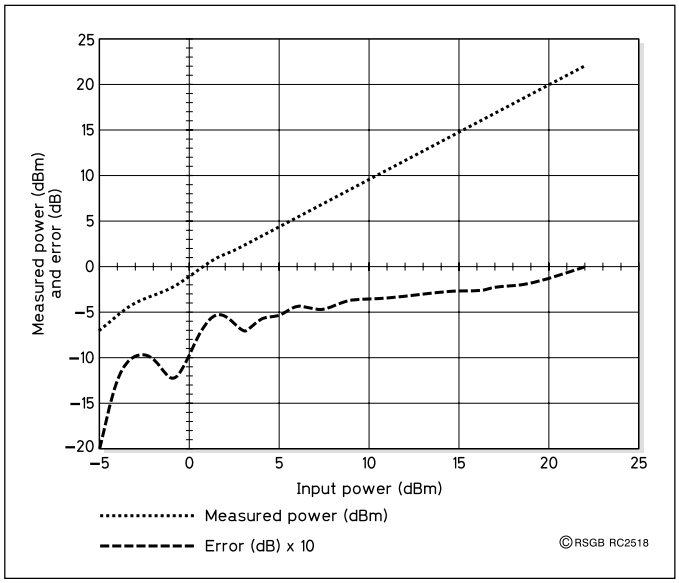


Fig 8: Measured vs Actual Power at 10MHz on the 200mW range.

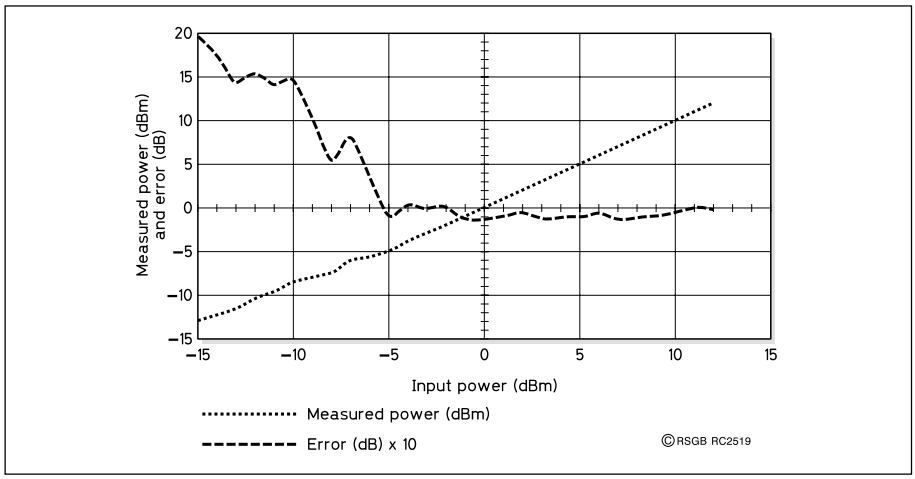


Fig 9: Measured vs Actual Power at 10MHz on 20mW range.

CONCLUSION

THIS ARTICLE HAS described the design and construction of a linear reading power meter capable of measurement in the range -9dBm to +22dBm (125µW to 150mW) with an accuracy about of 1dB (~20%). The instrument has a frequency response flat to within 1dB up to 280MHz. We have also shown how to calibrate the power meter with an ordinary digital multimeter.

ACKNOWLEDGEMENT

WE WOULD LIKE to thank all the members of the Crawley Amateur Radio Club for their help in developing these ideas. Particular thanks are due to G0SQF for his suggestion of using a two-bulb approach and to G3VJM for the photographs of the equipment.

APPENDIX 1

LINEARITY APPROXIMATION

The key components of the RF power-measuring head are shown in **Fig 10**.

When the power measuring bridge is balanced $R_b = 100\Omega$, and $V_b = V/2$. When the RF input power is zero, the power dissipated by the bulb (P_b) is given by:

$$Pb = \frac{\left(V/2\right)^2}{100} \times 1000\text{mW} = 5/2\, V^2\text{mW}$$

When RF power is applied to the bridge, half of it is dissipated in the 100Ω resistor, and half in the bulb. This RF power heats the bulb and reduces the DC power needed to heat its filament to the temperature at which its resistance is 100Ω to P_b'. The voltage across the RF head is thus reduced by ΔV to (V-ΔV). From this, it follows that:

$$\begin{aligned} P_{rf} &= 2(P_b - P_b') \\ &= 2\left(5/2\, V^2 - 5/2\,(\text{V} - \Delta V)^2\right)\text{mW} \\ &= 5V^2 - 5V^2 + 10V\Delta V - 5\Delta V^2\text{mW} \\ &= 10V\Delta V - 5\Delta V^2\text{mW} \end{aligned}$$

For small RF power levels ΔV is small and ΔV^2 tends to 0, and can hence be ignored, hence:

$$P_{rf} = 10V\Delta V\text{mW}$$

To demonstrate the validity of ignoring the term ΔV^2, consider the case of a head that has V = 9.61volts. The worst case on this instrument occurs at 200mW, where the instrument overestimates the power by 29mW. This corresponds to an error of about 0.6dB, ie 14%.

Note that 10V is a constant and thus ΔV varies linearly with the input RF power. V can be measured directly with a DVM when no RF power is applied, and the coefficient

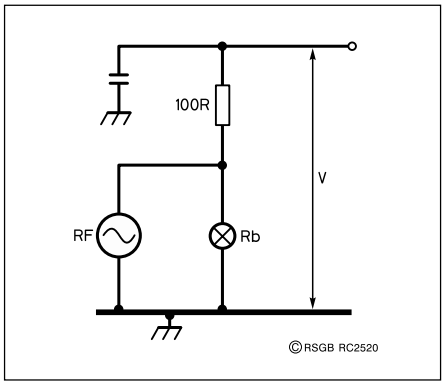


Fig 10: Key components of the RF power measuring head.

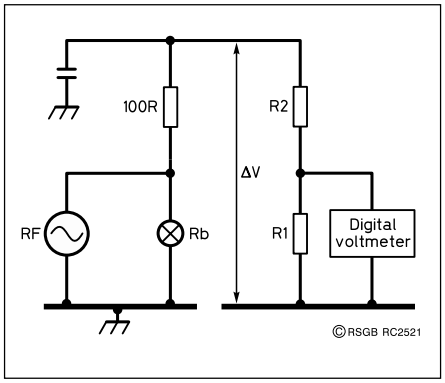
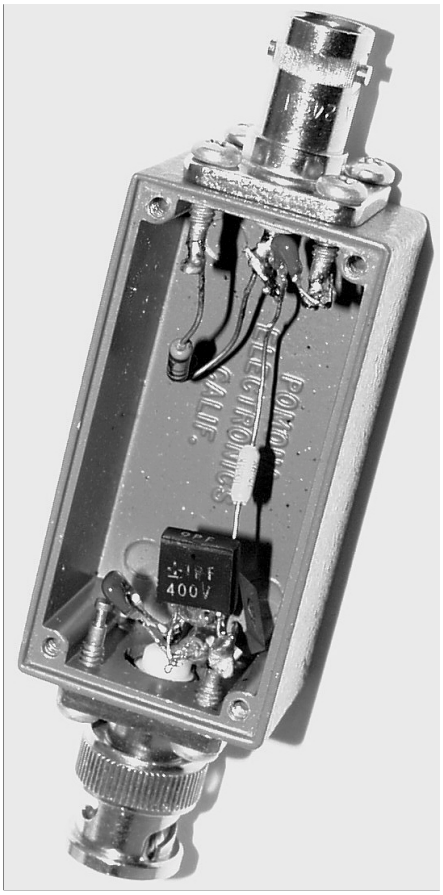


Fig 11: Scaling the output of the RF power head.



Internal view of the earlier two-bulb external RF head.

10V can thus be calculated. Measuring V is all that is required to calibrate the RF head so that P_{rf} can be measured directly on a linear scale voltmeter.

The RF power meter is 'zeroed' by setting a voltage reference to V (**Fig 11**), the voltage applied to the RF head to achieve balance when no RF power is applied. The voltage difference between the voltage applied to the RF head when RF power is applied, and the reference voltage (V) is ΔV. The voltage measured by the DVM is given by:

but given that

$$P_{rf} = 10V\Delta V\text{mW}$$

$$V_m = \frac{P_{rf}}{10V} \times \frac{R_1}{(R_1 + R_2)}$$

Rearranging, the required ratio of $R_1/(R_1+R_2)$ is:

$$\frac{R_1}{(R_1 + R_2)} = \frac{10VV_m}{P_{rf}}$$

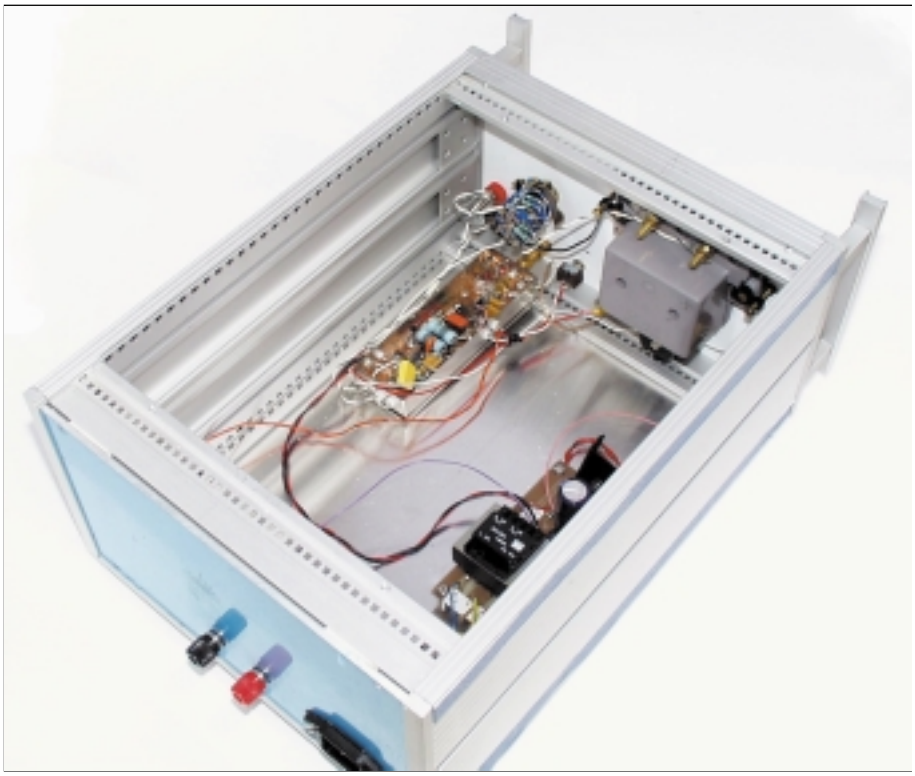
For a full scale of 200mV, corresponding to 200mW, and a zero RF bias voltage of 9.61V at the RF head (in the author's RF head), the ratio of $R_1/(R_1+R_2)$ = 0.0961. Similarly, for a full scale power of 20mW, $R_1/(R_1+R_2)$ = 0.961.

Power (dBm)	Power (mW)
23	200
20	100
17	50
15	32
13	20
10	10
7	5
5	3
3	2
0	1
-3	0.5
-5	0.3
-7	0.2
-10	01
-13	0.05
-15	0.032

Table 1: Power expressed in dBm.

Error (dB)	Error (%)
1.4	38
1.2	32
1	26
0.8	20
0.6	15
0.4	10
0.2	5
0	0
-0.2	-5
-0.4	-9
-0.6	-13
-0.8	-17
-1	-21
-1.2	-24
-1.4	-28
-1.6	-31

Table 2: Percentage error expressed as dB.



Internal view of the analogue version of the Crawley Power Meter.

APPENDIX 2

THE USE OF dB AND dBm

The use of decibels as a measure of relative power is familiar to the vast majority of radio amateurs. The output power of an amateur transmitter must be recorded in dBW, or decibels relative to 1 watt. In this feature we use the term dBm to mean power relative to 1mW into 50Ω. This is a standard unit of power used in professional circles to specify the output of signal generators and other low power devices. Although the Crawley Power Meter indicates the measured power directly in mW, it is convenient to use dBm to describe its performance. This is because the use of dBm allows us to display the linearity and accuracy over a wide dynamic range. For reference, **Table 1** shows the relationship between dBm and power and **Table 2** shows the relationship between decibels and percentage error in the reading.

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[2] 'Simple Practical RF Detectors', p12-4, *The VHF/UHF DX Book*, edited by Ian White, G3SEK.

[3] 'The Microwatter', by Denton Bramwell, K7OWJ, *QST* June 1997; or 'RF Millivoltmeter', p12-5, *The VHF/UHF DX Book*, edited by Ian White, G3SEK.

[4] 'A Simple Digital Power Meter', by Dave Roberts, G8KBB, *RadCom*, July 1999.

[5] Yearbook of the Institute of Radio Engineers 1931, p100. Tentative suggested methods of testing and rating radio transmitters and antennas.

[6] 'Accurate RF Power Meter for the HF Bands', Ian Braithwaite G4COL, *RadCom* December 1985.

[7] 'G4COL's simplified RF Power Meter', Technical Topics, *RadCom*, May 1986.

[8] 'Accurate Low Power RF Wattmeter For High Frequency and VHF Measurements', by James Bowen, WA4ZRP, *Ham Radio*, December 1977.

[9] Classically, a meter's internal resistance is measured by applying a voltage to the meter to achieve full-scale deflection, and then adjusting a series resistor to achieve 50% deflection. At this point the meter's resistance is equal to the series resistance. The series resistance is then measured with an ohm-meter. Modern DMMs however pass so little current through the movement that they can be used to measure the resistance directly, without damaging the meter movement. ♦

Crawley Power Meter with analogue readout, shown with its external RF head.